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AN

ESSAY

ON THE

CIRCULATION OF THE BLOOD.

AN ESSAY

ON

THE FORCES

WHICH CIRCULATE THE BLOOD;

BEING AN EXAMINATION OF

THE DIFFERENCE OF THE MOTIONS OF FLUIDS IN LIVING AND DEAD VESSELS.

By CHARLES BELL, F.R.S.E.
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1819.

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TO

JOHN ABERNETHY, Esq.

My Dear Sir,

AS I have often thought of you whilst writing this Essay, it appears therefore natural that I should inscribe it to you. I am sure you will peruse it with the indulgence of a friend.

At this time I feel, in common with the members of our profession, particularly indebted to you. By your improvements in Surgery, you have given into our hands new powers; and by the independence and liberality of your conduct, as much as by your acquirements and your talents, you have been an honour to our profession. But, above all, I feel grateful to you, that you have distinguished that part of the profession to which you belong, from a class of writers who, in seeking to associate themselves with distinguished men in philosophy, have adopted the worst part of what is peculiar to them. In France, during the period of the Revolution, two of the most celebrated anatomists and physiologists of that country were carried with the prevailing fashion of the time; and incorporated into their works the sentiments of Helvetius, Mirabeau, and other philosophical writers. These sentiments may be traced, like a turbid stream in pure waters, through some of the works of our own country. Originally these were not the opinions of the students of nature, but of secluded men; and the morbid excess of feeling which drove them to retirement, gave to the expression of their conceptions a fervour which might be their apology. But when, without that embellishment which genius can throw over them, we find them unnaturally joined to the demonstrative evidences of anatomy, they appear to me, as they have done to you, false in themselves, and quite foreign to the occasion.

No man ever received more hearty applause than you did in the conclusion of your discourses to the College; because you spoke what every man felt to be justly conceived, as well as eloquently delivered. You adapted yourself to the more matured judgment of the College; and you carried the hearts of the students with you by the spirit and animation of your discourse. Had you done violence to our most deliberate opinions and our best feelings, we should have regretted it indeed on your own account: but we should also have been indignant that our Professor chose to take advantage of his situation, to produce a distaste of our proper studies, and to deprive us of those reflections which support us through a painful profession.

Your younger colleague in the chair of the College of Surgeons thought it unbecoming to restrain the expression of opinions, however abstruse and delicate, however remote from the subject of his lectures. He spoke of freedom;—and of tearing the gown off his own shoulders, if he was to be controuled in any degree. By his surprise at the notice you have taken of him, it appears that he has not understood the difference betwixt the individual and the office he holds. If he had justly estimated the value of the gown at the time he received it, he would better have comprehended the motive of that attention he has met with. He stood as the organ of the College; and it is too much to expect that those who came there to support him as the Professor of the College, should be brought to sanction, by their presence, doctrines which they know to be founded in error.

This is now the third time that I have seen the influence "of lean translations out of French," upon our students; and it has appeared to me to subdue, in a remarkable manner, their love of the works of nature; and to cool that enthusiasm which should belong to their peculiar studies, and their time of life.

They know not how much they lose by being seduced from a just philosophy, in favour of such speculations, the offspring of vanity and seclusion; and leading to a stupid and sterile materialism. I would desire no other guard upon the mind of a youth against the infection of those notions, but that he should study some department of natural knowledge deeply: not in men's written opinions, which are so often distorted by passions and obscure motives, but in the object itself, in nature; above all, I would recommend to his observation the structure of animal bodies.

The human body, though deprived of what

gave it motion and feeling, is still a plan drawn in perfect wisdom. The student who comes to the examination of it with right notions, will think he is admitted to a great privilege; he opens, as it were, the volume of nature to see things near at hand. With men of talent the interest increases every day. Those of a different stamp, and who possess neither just feelings nor good taste, must treasure some of the sentiments and expressions of your colleague with particular satisfaction.

A man possessed of that humility which is akin to true knowledge, may be depressed by too extensive a survey of the frame of nature. The stupendous changes which the geologist surveys, the incomprehensible magnitude of the heavenly bodies moving in infinite space, bring down his thoughts to a painful sense of his own littleness: to him "the earth, with men "upon it, will not seem much other than an "ant-hill, where some ants carry corn, and "some carry their young, and some go empty, "and all to and fro, a little heap of dust *." He is afraid to think himself an object of Divine care. But when he minutely regards the structure of his own body, he learns to consider space and magnitude as nothing to a Creator. He finds that the living being which he was about to contemn, in comparison with the great system of the universe, exists by the continuance of a power no less admirable than that which rules the heavenly bodies. He sees that there is a revolution, a circle of motions no less wonderful in his own frame, in the microcosm of man's body, than in the planetary system; and that there is not a globule of blood which circulates, but possesses attraction as incomprehensible and wonderful as that which retains the planets in their orbits.

The animation with which you have answered opinions on subjects which regard the

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* Bacon.

happiness of others, and the mildness with which you have noticed criticisms on yourself, afford an excellent example.

I consider it the peculiar happiness of a life such as yours has been, which private virtue embellishes as much as those services you have done to Science, that you can raise your voice against false opinions without a suspicion of any motive but the most generous and pure; and that you can exert your powers on such a subject to crown all your former labours.

I am, my dear Sir,
With every Sentiment of
Friendship and Esteem,
Very truly yours,
CHARLES BELL.

Soho Square, April, 1819.

AN
ESSAY
ON THE
CIRCULATION OF THE BLOOD.

PART I.

AN Essay on the Circulation of the Blood conveys to most readers an idea of presumption in the author; as if he were about to put a rude hand on the honours of our great countryman. To others it gives only an impression of utter hopelessness of useful results. But in giving instructions in the first principles of that profession, which is to be the business of their lives, to men who have been accustomed to a just method of reasoning on subjects of philosophy, the Author has felt in some degree humbled in entering on the circulation of the blood. He has been obliged to expose to them the want of just principles, and the substitution of mere authorities, in explaining by what force the blood is circulated. After many years he still finds the matter encumbered with difficulties.

The object of this Essay is to shew that, in one of the most common subjects of physiology, we give our assent to what we do not perfectly comprehend. We acknowledge the circulation of the blood, without attempting to remove those objections which every intelligent student is capable of offering to it. It is my purpose to state those objections; and to offer to my reader the course of reasoning with which I have met them when treating the subject in my lectures.

I shall not enter at present into an investigation of the whole of this curious subject, but confine myself to such points as appear particularly to require illustration.

If I am performing an operation on the living body, a stream of blood is thrown out from the exposed surface;—an artery, the calibre of which is not greater than a pin, will throw out a stream of blood to the distance of three or four feet. Upon injecting the vessels of the dead body with water, whatever may be the force with which I use the syringe, the fluid may be made to ooze from the orifice, but not to rise in a jet.

While the blood is flowing in this powerful jet from the vessel of the living body, it may, by an application of styptics, be arrested in the open mouth of the artery. No such effect can be produced on the dead body: although the water only oozes from the orifice, no application will stop it. It therefore appears that there is a facility given to the course of the living fluid in the living vessels that is lost in the dead tube. Simple and obvious as this fact is, the neglect of it has given rise to the most remarkable discrepancies in the observations and conclusions of learned men.

How are we otherwise to account for Borelli saying that the heart has a power of 180,000 lbs. and Keill that it has a power equal only to eight ounces? How are we to account for Senac estimating the pulsative power of the crural artery to be sufficient to raise a body of 400 lbs. while a very few pounds weight, placed on the artery, will certainly close it against the entrance of the blood.

As the blood flows uniformly and without pause in the veins, and as, at most, two powers only are operating on the column of blood, that of the heart, and that of the arteries, it is affirmed that the power of the heart's contraction reaches through the whole extent of vessels.

Further, Haller has asserted, that the impulse from the contraction of the heart moves the blood onward through the extremities of arteries the sixth part of a line in diameter. And in all the length of an artery, (as Senac observes,) the blood is seen to flow with greater impulse during the contraction of the heart, and with diminished force during its diastole.

Here then is the first objection which a student, who has been accustomed to reason philosophically, will start to the circulation of the blood. He sees that the arteries and veins are divided and multiplied to an incalculable degree of minuteness; that the blood is every where, and every where moving with rapidity. He recollects how the attraction operates betwixt the fluids and the solids spread out in contact, upon a surface many thousand times the extent of the surface of the body. The question at once occurs to him what power must the heart possess to propel the blood against this influence? He turns to the heart; and, although he cannot calculate the power of the living fibre, he sees that the mechanical checks which direct the blood, are so weak in texture, as to be unable to bear the weight even of a few pounds or ounces; and, meeting with no answer to his enquiries, he already begins to look back with regret on those more philosophical studies which he followed at college.

The excellent Dr. Robert Whytt, in his enquiry into the causes which promote the circulation of the fluids in the small vessels, says that, "however easy it may appear to some authors to account for the motion of the fluids in the small vessels of animals, yet, whoever considers the resistance that a fluid, moving through the aorta and all its branches, must meet with from friction, and adds to this the mutual attraction and cohesion betwixt the particles of the fluids, and the sides of the vessels in which they move, will not only see that there is some difficulty in this matter, but suspect that neither the force of the heart, nor the alternate contraction of the larger arteries, are sufficient to drive the fluids through the smallest vessels of the brain, testes, and many other parts of the body."

The ingenious Dr. Hales said, "If we could be so happy as to find a liquor of such a due consistence, as to pass freely through from the arteries into the veins, as the blood does in its natural state, then many curious experiments might in this manner be tried on several parts of the body."

From these celebrated men we have the statement of the difficulty; a difficulty which Dr. Hales encountered in all his experiments, however ingeniously contrived: the finest fluids could not be made to pass through the vessels of the dead animal, with the same freedom and velocity as the natural blood, though thick and viscid.

But is it true that the blood is viscid while in the living vessels? "Fluidity being," as Mr. Hunter has said, "necessary at the time of circulation, for its motion, distribution, and the easy separation of its parts," are we to suppose that this necessity is imperfectly fulfilled? The blood is the most subtle fluid in nature, and passes where our finest injections cannot be made to enter. And there seems reason to conclude, not only that the coagulation of the blood is an act of dying, but that the viscidity of the blood (as we see it in the fluid part out of the animal) is also a state incompatible with life and circulation.

Mr. Hunter has said that coagulation is "an operation of life: it is," says he, "particle uniting with particle, by the attraction of cohesion." I am forced to reject the first part of the opinion, and adopt the latter. Coagulation is the act of death; by which the blood, hitherto preserved fluid, suffers an attraction of its particles, and becomes solid.

But it is not only by the attraction of the particles among themselves, that the new property is exhibited in the coagulum, it is also rendered manifest by its attraction to the sides of vessels, or to any contiguous surface. When an artery is cut in the living body, the hæmorrhage will be the more profuse the less the injury which the coats of the vessel have sustained; but neither a torn artery nor a bruised artery bleed.

If the limb be torn off, and the artery lie with its mouth open, the blood is coagulated and attracted to the coats of the vessel. If we injure a vessel while the blood is flowing, the blood is attracted to the mouth of the vessel, and the bleeding stops. Nip the blood vessel with the fingers, or with the forceps, and the stream of blood is stopt; although in both these instances the mouth of the vessel be open.

This, it has been suggested, may be owing to the air admitted to the blood, to the change hence induced, and to new properties in the blood. But the same effects follow an internal wound, where no air can penetrate; and the coagulation and the attraction take place to a depth in the vessels which does not admit of this supposition.

These facts lead us to understand the difference betwixt the course of the blood through living vessels, and the flowing of water through dead tubes!—De Gorter has shown by experiments that, in order to push the fluid through the small vessels of dead animals, it is requisite that the fluid should fall from a height the double of what is required to equal the power of the heart. But did the fluid in the dead vessel spring as from a divided artery?

How much greater must the pressure be to make a small vessel throw out the fluid three or four feet? The phenomenon to be explained, without which we need not advance a step further in reasoning or experiment, is this,—from the living surface the blood rises freely, and in so small a jet that it is not perceived except when the blood is scattered on a white part of the dress. We cannot imitate this in the dead body. Again, when a living artery is giving out its blood in a stream, it will stop, and the blood suffer coagulation merely by injuring the vessel, although the mouth of the vessel remain open. When I witness the force with which the blood spouts from a wounded vessel, and when I consider the amazing number and minuteness of the vessels through which the blood is flowing at the same rate, and when I recollect the weakness of the heart, and the delicacy of its mechanism, I am brought to this conclusion. Philosophers have been estimating a resistance which does not exist in the living frame. They have been in the old error; estimating the powers of a living body by the result of their experiments on dead matter. They have been estimating the course of the blood, (which has properties different from what it exhibits out of the body), as they would water conveyed in lifeless tubes.

Attraction is a term used to denote the power which draws bodies together; a property the most universal in nature; so that we may say every particle attracts every other particle. It is universal in dead matter, and necessary to the frame of the world. Without some such principle there could not be any motion; and, without it, motion would soon perish. Are we prepared to admit that this universal attraction of fluids and solids is *negatived* in the vessels of a living body,—that the great Architect, instead of accumulating forces to overcome the vast resistance, has annihilated it, and rendered a smaller force sufficient to the end, and at the same time consistent with the delicate texture of our frame.

If this fact were satisfactorily established, how surprising and admirable would it appear, that the power which orders every thing in dead matter, by which all motions are begun, by which heavy bodies descend, light bodies float, rain falls, and vapour ascends, on which depends the flowing of waters, as well as the stability of solid fabrics, should be dismissed in this instance, as incompatible with the motion of the fluids, and consequently with the life of animals.

There is no other rational theory of secretion but that which supposes the chemical affinities of the blood to be changed by the influence of life in the smaller vessels. But that which modifies attraction may discharge it.

In this sense perspiration is a secretion; and, although arguments from analogy are dangerous, yet as the skin is a surface exposed to our observation and experiments, I shall apply my hypothesis to it.

If a glass tube be attached to the artery of a horse, the column of blood will suddenly rise in the tube, marking the force of circulation. If the animal be bled from another vessel, the blood will descend in the column, as the force of the circulation is enfeebled. When the blood is very low, and the animal dying, the surface will break out profusely in perspiration. It must be concluded that the force of internal impulse is not the cause of perspiration. Again, the most persevering efforts in injecting the vessels will never bring the water through the pores of the skin; and if a dead body be carried near the fire, the heat will not bring out one drop of fluid from the pores of the cuticle.

The examination of the pores of the skin, and a very simple experiment, will explain the phenomenon. The pores of the skin are tubes formed by processes of the cuticle which run deep into the cutis vera: they are capillary tubes. To exhibit the attraction in capillary vessels, I drew out a tube of glass to some degree of minuteness, and, breaking off the extremities, I dipped the end in wine; the wine rose in the tube by capillary attraction. I did this in the beginning of summer: on the commencement of winter I could not observe that the fluid was diminished. I was aware of the fact before I made the experiment; but I did not conceive that the attraction of the fluid for the tube would have so effectually resisted the attraction of a dry atmosphere. We perceive now how impossible it is that evaporation or perspiration can take place from the capillary tubes of the skin of the dead body. What then produces perspira tion? Is it not a process of life which destroys the attraction and lets off the fluid? And is it not the same negative attraction which permits the blood to flow in the smaller vessels, without which they would retain the blood and stop the circulation?

I am inclined to think that this negative attraction is not without its influence upon the lengthened excretory ducts of glands, when there is a sudden flow; for example, of bile or saliva; and how the convoluted vasa deferentia testis are capable of discharging their fluids without it, I am unable to conjecture, when I consider their almost incalculable length, and the smallness of their cavity.

Surgeons have miscalculated the force of arteries almost as much as physiologists have mistaken the power propelling the blood. After reading the means of stopping hæmorrhage, would not one suppose that it required some particular force of body as well as energy of character to stop the bleeding from a principal artery? What stuffing of clothes and pressing of one hand over the other! But what in truth is requisite to stop the pulsation in the most powerful artery? The pressure of the little finger is sufficient.

See with what slight force the blood moves along the veins on the back of your hand. Yet slight as the pressure is which will stop the flow of that blood in those veins, and slight, consequently, as the impulse of the blood must be, the blood will make its way back to the heart, throwing down all the impediments which you have calculated upon, and open the heart itself.

When Mr. Hunter laid bare the radial artery of a dog, and saw it contract, and, on cutting it across, saw the blood oozing only, and not flowing in a stream, he concluded that the obstruction of the blood was owing to the contraction of the artery. Can we agree to this conclusion? Before this experiment was made, did not the blood flow rapidly through the capillary extremities of that vessel some fifty times smaller than the trunk even in its contracted state? Did the contraction of the artery bring it to the diameter of one of its own secondary or ternary branches? If it did not, it could not be the smallness of the calibre that stopt the blood when the artery was divided. It was the injury from exposure, and the dissection, and the consequent attraction that began to prevail betwixt the vessel and the contained blood. In such a case there is blood contained within the vessel; but that blood is coagulated. I have examined the radial artery of a man cut across by a musket ball, when the blood stopt spontaneously; I found the blood coagulated for an inch in the length of the artery.

When vessels are divided in a wound, and the blood flows at first impetuously, then slowly, and when the red blood is stopt, and serum only passes, is it the contraction of the mouths of the vessels which retains the red globules? Let us follow the action out: presently pus mixes with the serum, and suppuration is gradually established. Globules larger than those of the blood are passed through the mouths of the vessels. Do the extremities of the vessels open and enlarge again? Then should the red blood flow afresh. Since this is not the case, we must conclude that, from the commencement of the retardation of the blood flowing from the divided vessels, the living coats are exercising an influence on the contained fluids. That the serum or the pus discharged are not merely the finer parts of the blood, percolating through the contracted vessels, but secretions, must be admitted, if we define secretion to be the blood changed through the influence of the living vessels. Without acknowledging the agency of the living vessels on the composition of the blood, we shall not be able to account for the changes performed on this fluid in the body or the difference of experiments made in chemical vessels, and in the tubes of the living frame. But grant that there exists a mutual influence of solids and fluids peculiar to life,—then the step is easy to admit also, that the common attraction of cohesion is dimissed, and then our view of the subject of the circulation of the blood is consistent.

We have no longer to estimate a force of attraction too great for the heart to overcome, or to suppose forces in operation quite inconsistent with the weakness of our frame. The motion of the blood is facilitated by the abstraction of a power, instead of an enormous accumulation of force; and the attraction is resumed, as in the case of an opened vessel, when necessary to the safety of the individual.

It is solely in this way that we can explain the fact which is every day before our eyes: that the blood circulates through vessels so small that we require a microscope to see them, and yet that not a drop flows from the trunk of those vessels, when cut across, although it be fifty times larger in the calibre.

It is difficult to account for the stopping of the blood, when the artery is torn, without admitting attraction and coagulation to be consequences of the injury; and it seems to me impossible to account for the circulation of the blood through myriads of small capillary vessels, by the impulse of the heart, without supposing that there is in this living and healthy state of the body an absence of that attraction which is universal in dead matter..

In drawing this conclusion, I have proceeded on the idea, that if the principles of mechanism, or of chemistry, be admissible in the explanation of vital phenomena, they are still incapable of solving our difficulties. When matter acquires life, it acquires also qualities and powers which it had not before, and which it loses the moment that life is extinguished. The extinction of life, so far as it relates to the body, being nothing but the loss of these properties. It may be argued, living powers are superadded to those of inanimate matter, when it is taken into the living frame, but none of its former properties are taken away and destroyed. Our blood gravitates, as we see, in the veins of the lower extremities: and when extraneous force acts upon a living body, it is as inert as when it is dead. But this relation of an animal body to the surrounding world, in respect to its gravity, corresponds with endowments even of our senses, which hold a relation with what is around us. Gravitation is necessary to the exercise of our senses as well as to the agency of the body. That the living body can begin a motion ought, I think, to lead us to consider it in a very different light from the class of inanimate objects around us, although holding certain relations to those objects.

This reasoning may not be satisfactory. Some may still say it is not safe nor philosophical, to suppose that the matter of living bodies parts with any of its qualities; and that it is by addition, not subtraction, that the difference betwixt the two states of matter, the animate and the inanimate, is produced. But is there no such modification of dead matter? Does heat produce no difference in the running of fluids through tubes? Does electricity produce no such modification of attraction betwixt fluids and solids? In water contained in glass, metal, or wood, we have attraction in different degrees; but in mercury we have the contrary, for it is repelled by glass or iron.

Those who would object to my hypothesis, on the ground that it implies a violation of the laws of nature to suppose attraction destroyed or modified in living vessels, may find in these considerations a new reason of acquiescence, since even in dead matter we have instances of nearly a similar result.

I am aware that, in the second part of this Essay, I shall weaken my arguments as to the necessity of supposing the attraction betwixt the fluids and solids destroyed, since I am there to shew how powerful the arteries are in propelling the blood. But, admitting the power of the arteries, and, on the other hand, considering that the whole body is a tissue of tubes conveying fluids, I think we shall see reason to conclude, that if the fluids were attracted to the solids at all times, and through the whole system, they could not be moved forward. They must be like the sap in a tree felled at undue season, which remains stagnant until the timber rots.

PART II.

IN this second part I intend to treat of the action of the arteries, to shew what powers they possess of circulating the blood, and how they vary in activity, independently of the heart's action: at one time diminishing the velocity of the blood, and at another encreasing it in a remarkable degree. It is especially intended to draw the attention of the reader to the different forms of the arteries, and to explain the uses of this variety.

In what follows, as in what has preceded, I have endeavoured to discover the truth by the examination of the structure, and the observation of the phenomena of life, without torturing living animals. It is too common a belief that, in physiology, experiments on living animals is the best and surest way of pursuing an enquiry, although it be certain that the supposed issue of experiments, is as much affected by the preconception, as the process of reasoning can be. The experimenter on brutes is not to be called a philosopher merely because he goes counter to the natural feelings of mankind; nor is he the more entitled to favour, that he gives a character of cruelty to the Medical Profession, thereby contracting its sphere of usefulness*. It is but a poor manner of acquiring fame, to multiply experiments on brutes, and take the chances of discovery. We ought at least to try to get at the truth without cruelty, and to form a judgment without having recourse to torture. At all events, it is our duty to prepare for experiments upon living animals by the closest previous application of our reason, so that we may narrow the question, and make it certain that advantage shall be gained by the experiment.

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* That I have known the best and most virtuous men hold a different opinion, I must allow. But I have not been able to suppress the expression of my sense of this matter, that dissections of living animals attended with protracted suffering must be wrong. I can affirm, for my own part, that conviction has never reached me by means of experiments on brutes, neither when I have attempted them myself, nor in reading what experimenters have done. It would be arraigning Providence to suppose that we were permitted to penetrate the mysteries of nature by perpetrating cruelties.

Before entering on my proper subject, let me suppose, that an experimenter were to affirm that arteries do not dilate and contract, and were to propose to support his opinions by some fifty experiments on living creatures; I might be permitted to say to him,—

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which are ever against our instinctive feelings. I am, therefore, happy in believing that the examination of the natural structure, and the watchful observance of the phenomena of life, will go farther to give us just notions in physiology than the dissections of living animals.

Before you commit these cruelties, consider well, whether the object of which you are in pursuit be capable of demonstration in the living tube. Before you open the dog's or the sheep's throat, to look at the pulsation of the carotid artery, consider the quantity of blood sent out from the heart at each pulsation, estimate how much of this is expended on the elongation of the artery, estimate the number and length of the arteries, and put this question first to yourself,—Supposing that the artery dilates, is it in such a degree that my eye shall be able to distinguish it?

Not satisfied with this consideration, our experimental philosopher may yet suspend his hand, and reason thus:—All physiologists admit that the artery is elongated at each contraction of the heart: I may as well see, by examination of the coats of the dead artery, whether they be as yielding and elastic in their transverse direction, as in their length;

for if it prove to be so, and if it be true that pressure on fluids extends in all directions equally, then while the artery is dilated in length, it must suffer a proportionate dilatation in breadth.

But this philosopher having the knife in his hand, and the animal bound before him, is, notwithstanding, resolved to try the experiment. That is, he dissects the living animal; or, as it is more cautiously expressed, he lays bare the artery,—he sees it move with the systole and diastole of the ventricle of the heart,—but is absolutely unable to discover any change in the diameter of the vessel. Accordingly, he proceeds to prove by multiplied experiments on living creatures, that there is no dilatation of an artery, but only an elongation: yet, if he had reasoned on the matter, one, instead of fifty experiments, might have satisfied a reasonable man. As thus;—the carotid artery is six inches in length; half an inch in diameter; it elongates at each contraction of the heart a quarter of an inch, and, of course, rises from its bed in a curve to accommodate itself to its confined place. Supposing that it dilates in breadth in the proportion of its elongation, ought I to see this dilatation? Dividing the inch into twelve parts, the length of the artery is seventy-two twelfths, the diameter six-twelfths. The motion of dilatation is to the motion of elongation as six to seventy-two; that is, twelve times less in degree. It further appears from experiments that the longitudinal motion of the carotid artery is in so limited a degree, that it cannot be at all times observed, but only in favourable circumstances. This being granted, is it reasonable to expect that a lateral motion of the artery should be observed, which is twelve times less in degree than the longitudinal motion which is caused by the same impulse, and is taking place at the same instant of time? Thus, by omitting to question himself before questioning the animals under his knife, an experimenter may be led on to compose a volume of experiments.

There are sufficient reasons for believing that the arteries might propel the blood without the aid of the heart, if the uniform motion of the blood through the body were the only end of the circulation. We have reason to believe, that the heart belongs fully more to the lungs than to the body; and that its chief office is as a regulator of the circulation and respiration, preserving at all times a due relation betwixt them. Yet it cannot be denied that, constituted as animal bodies are, the heart has a powerful effect in propelling the blood. I have seen with the microscope, in cold blooded animals, the red globules of the blood propelled in pulses through the extremity of the vein; and, therefore, what is said by one physiologist of the blood flowing in a uniform stream from the extremities of arteries, and by another, of non-pulsating arterial extremities, is probably founded in error, or in inaccurate experiments.

But although it were admitted that the force of the heart is sufficient to carry the blood through the whole extent of the arterial system, it cannot be made to account for the inequalities which we observe in the force of the arterial actions. It cannot account for increase and diminution of secretion; for sudden and partial growth; for wasting and decay of parts, while the general body is vigorous. It will not account for an organ being plentifully supplied with circulating blood one hour, and the next left with a diminished quantity. Ought not these facts to be accounted for? In what state is our physiology when we must overlook these most common and obvious occurrences? To suppose that the heart is the only engine circulating the blood, or even that it is the principal cause of the motion of the blood, must leave us in perfect astonishment when we see it ossified in its substance, or encumbered with a tumour which surrounds it wholly, and adheres to it on all sides! *

Some physiologists have denied the iritability of arteries, they have neglected the evidence of anatomy, and the experiments of Mr. Hunter, and then have contrived clumsy experiments the better to correspond with their own fancies.

They have not enough considered that muscles will sometimes resist all stimuli but that of their proper agents. It would be too much to infer that the iris is not muscular, because

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* See specimens in my Collection. But of this kind the most extraordinary case is that narrated by Mr. Allan Burns; where "the whole extent of the pericardium covering the "ventricles, and the ventricles themselves, except about a "cubic inch at the apex of the heart, were ossified and firm "as the skull."

it does not act upon being pricked! We see that the heart, after it is exhausted, and refuses to act whatever stimuli be applied, will contract when it is distended, because distension is its natural excitement. For the same reason an intestine will revive and act upon being distended with air, though it will not upon being pricked with needles. How then shall we contrive to excite the arteries in imitation of their natural stimulus? Or, supposing that we succeed in causing them to contract, how shall we perceive the action?

Hales having introduced a tube into the descending aorta of a living animal, and having raised a column of water which, by its pressure, might inject all the branches with a force equal to the heart, he cut the intestines in such a manner that the small branches were divided in the length of the intestine on the side furthest from the mesentery. He found that a certain quantity of water passed from the cut vessels in forty-six seconds, while the same quantity of brandy took sixty-eight seconds; and on a second trial seventy-two seconds. He found, by the same mode of experimenting, that warm water, of the temperature of the animal, passed off much quicker than cold water from the pump. The natural inference from this experiment is, that the cold water and the spirits excited the muscular fibres to diminish the calibres of the vessels, and hindered the course of the fluid.

It may be seen at any time that the arteries of the turtle exert a muscular power. The viscera of a turtle having been sent from a hotel in Covent Garden to Windmill Street, the heart was still beating, and the intestines contracting. On attempting the injection of the aorta, it could not be dilated with all the force of the syringe. But, next day, when the parts were relaxed in death, when the intestines no longer exhibited their vermicular motions, the arteries dilated under the pressure of the syringe, and admitted the injection freely.

Mr. Hunter's experiments appear to me conclusive. He proves that the arteries contract with a living power, distinguishable from elasticity, by its ceasing with life. It is not only offensive to see such authorities as Haller, Whytt, and Hunter disregarded, and their experiments and conclusions set at nought; but it is quite evident that Science cannot be progressive, unless we pay respect to the great men we have lost. I read in a French work where, with the utmost indifference to all we know through the labours of these men, it is written, that there are no muscular fibres in the arteries, not even in the aorta of an elephant; and that experiments have been made in every possible way to make these supposed muscular fibres act, but to no effect. The author then speaks with a soft indulgent regret of those who have been so long deceived into a belief that arteries have muscular or irritable fibres.

Suppose that a physiologist were to put a pipe into the crural artery of a dog, and to force out blood and water at the corresponding wound in the vein, so as to make the jet rise from the wound, could it be affirmed on such proof that the heart is sufficient to the circulation, and that there is no need of muscular arteries? The plain answer is, that this is not all that is necessary to be accomplished through the apparatus of circulation. That artery into which the tube is introduced, can be made in the living body to partake of excitation; to deliver a greater or lesser volume of blood in a given time; to drive it with more evident pulsation, and further into the extreme vessels. How then can this partial increase happen if the power be in the centre only? How can an artery contract, how can it enlarge in a permanent manner, if the whole power be given to the heart? How, if the artery possess elasticity only, can these phenomena be explained?

Water will find its level; nor does it signify whether the tube be straight or crooked, through which it descends; it will spout up to the same level with the water in the reservoir. But the ajutage or spouting pipe of a jet d'eau affects the motion of the stream. If the water rise from a small tube, it will not mount so high as if it were to pass through a large pipe supplied from the same reservoir. The larger the tube is, the water will spout the higher, provided the reservoir be kept full. To raise the jet to the highest possible degree, the ajutage pipe must not be turned up at a right angle, it must have a gentle easy curve. A polished round hole in the end of the pipe gives a higher jet than either a cylindrical or a conical ajutage; and a conical form is better than a cylindrical form for it. It is also found that the longer the pipe is, the larger it must be in diameter to give full effect to the pressure of the water in the reservoir. Thus even when water is flowing smoothly from the uniform pressure of a reservoir, the friction or attraction makes a remarkable difference according as the tube is narrow or wide, straight or crooked, ragged or smooth. How much more must be the impediment, if the fluid be propelled in a jet, as the blood is sent out of the heart. There will, I am sure, be no objection made to the following experiments, on account of their simplicity. I filled an elastic gum bottle with water, and contrived that a heavy body should fall upon it.

1. The mouth of the short tube attached to the bottle was a quarter of an inch in diameter; by the weight falling, and the sudden force of compression, the jet of water was conveyed twenty-two feet.

2. Putting on a small tube of an inch and a quarter in length, and the twelfth of an inch in calibre, the same weight falling, projected the water five feet only.

3. Having attached a tube one foot in length, and the fifth of an inch in diameter, the jet was thrown out eight feet.

4. On twisting the same tube round a rod, the jet was carried four feet.

The water in all these instances was flowing from the mouth of the tube, before the weight was allowed to fall.

We see how impossible it would be for the heart to propel the blood through the arteries and veins of different calibres and curves, with the same force or with any regulated impulse. As the resistance of a fluid is greater when a body is moved faster through it, so in the curved and elastic vessels of an animal body, the resistance will be the greater, the more sudden the impulse.

We have now to consider in what the vessels of a living body differ from rigid tubes.

1. They are elastic. 2. The course of the fluid through them is by sudden impulse; not as by the uniform pressure of water in a reservoir. 3. They are in possession of a living property; a power of contraction greater than the power by which they suffer distention.

It is this latter property of irritability that subverts all those conclusions which we would draw from the laws of hydraulics. And it is by inattention to this (I should be inclined to say obvious distinction,) that physiologists have been led to conceive that a curved artery is merely a means of retarding the flow of blood.

Mr. Abernethy, in his lecture at the College, having drawn on a board what he conceived to be the course of the vertebral artery, and contrasted the crooked course of this with a straight tube, said bluntly, nobody but a fool could believe that a curved artery was designed for any other purpose than for retarding the course of the blood. This, it must be confessed, is the general opinion, however it may be expressed.

Yet I believe that those who have adopted this idea, have their eyes closed upon the greatest beauty of the animal structure. I hope I shall be able to prove that the tortuous structure cannot be designed merely to retard the blood; and that this notion stands contradicted by the survey of the natural body and its functions, as well as by the effects of disease.

Let us attend, in the first place, to the difference in the form of an artery as it ascends and as it descends.

We find the arteries of the lower extremity less tortuous than those of the head. The arteries of the legs and feet run in a straight direction: we follow the arteries on the head, and, as they ascend, they turn upon themselves, and still mounting on the head, they become more and more twisted and reflected; and in the extreme branches, for example, of the occipital artery, the tortuous form encreases as they diminish in size, until they reach the vertex. As this fact cannot be denied, we may put it thus,—the arteries which carry the blood downward have less curvature than those which carry the blood upwards against the power of gravitation.

If a tumour grows upon the head, the artery of the temple, already tortuous, becomes three times more tortuous; it is seen twisting in its pulsation under the skin.

The arteries of the mamma in a woman giving suck, become remarkably enlarged, but more remarkably tortuous. The rami mammarii of the internal mammary artery I have seen twisted and as tortuous as the splenic artery. When the function of the gland ceases, the arteries lose their tortuous form, and diminish in size.

The tortuous form of the artery prevails wherever the part supplied is subject to occasional encrease of activity. The arteries of the uterus, those of the testicle, those of the stomach and spleen, those of the penis which serve for erection, are tortuous beyond all other examples in the natural structure of the body. When we witness the sudden activity which prevails in some of these organs, or the rapid growth of others (for example the uterus during gestation); and when in that state we see the arteries becoming more and more tortuous as the activity or the volume of the body encreases, how can it justly he asserted that the tortuous form of the artery is for the purpose of impeding the course of blood!

If, according to the notions of some physiologists, the arteries possessed only an elastic power which aided the power of the heart as the compressed air of the fire-engine does the forcing pump, what would the consequence be of a hole in the side of the vessel? Would not the elastic tube contract in consequence of the distention being diminished? The facility of escape having an effect upon the fluid similar to a diminished impulse. The reverse I hold to be the case in living vessels. An artery which is opened becomes the most active in the whole system while the blood continues to flow: hence bleeding from a distant vessel tends to stop the hemorrhage from a wound. But we require something more distinct than this assertion, and which shall amount to demonstration. The bleeding from the side of an artery would be too quickly fatal to give us time to make experiments, were we to attempt ascertaining the fact in this way: but may we not take the case of varicose aneurism, and call it an experiment without the cruelty and uncertainty which attend experiments. The varicose aneurism is formed in consequence of the lancet in bleeding, transfixing the vein of the arm, and entering the artery; the blood of the artery finds access to the vein; and in time a channel is made betwixt the artery and vein, by which the blood has an easy conveyance out of the artery back to the heart, without passing through the extremities of the arteries and veins. This, in effect, forms a perpetual drain of blood from the artery, without weakening the system. The effect of this upon the artery is most remarkable; and must, I think, decide the question at issue.

" The trunk of the brachial artery is con-
" siderably *enlarged* all the way down the
" arm, and its pulsation so strong, that it is
" apparent to the sight; a little above the
" bending of the arm the artery makes a *re-*
" *markable serpentine turn*, which raises up
" the skin, and, by the force of its pulsation,
" looks as if it were a beginning aneurism.

"But, notwithstanding the size and the force "of pulsation of the brachial artery *be much* "*more considerable than in the other arm*, "the artery at the wrist is smaller, and its "pulsation much weaker." Dr. Hunter, Med. Observ. and Enq. vol. 2.

So very singular a fact was not passed over by Dr. Hunter: his remark is pertinent to our present enquiry. "Whence is it," he says, "that the artery is enlarged all the way down the arm? I am of opinion that it is somehow the consequence of the blood passing so readily from the artery into the vein; and that it will always so happen in such cases: that it is not owing to any particular weakness of the coats of the artery like that in true aneurism, but is rather such an extension as happens to all arteries in growing bodies, and to the arteries of particular parts when the parts themselves encrease in bulk." I shall not attempt to reason on this state of the artery in varicose aneurism, until I present a similar consequence apparently from a different cause.

When the main artery of a limb is tied, the branches enlarge, and, by the inosculation of their extremities, they supply the lower part of the limb. But, during this change, their encrease in size is not so remarkable as their convolutions. While they enlarge, they become at the same time very tortuous.

To those who do not give themselves the labour of thought, this change seems very natural. They say you stop the great channel, and the lesser branches suffer the pressure, and are enlarged. But why does not the same take place in amputation? Why do these branches diminish in the one case, and enlarge in the other? For if the obstruction be the cause of their enlargement, then they ought to be most enlarged when most obstructed;

viz. in amputation. But the reverse is the case.

These facts, and many others, are inexplicable, unless we admit that the limb or organ supplied by an artery has an influence retrograde along the trunk of the artery that belongs to it. If we admit this, we can comprehend how the arteries finally contract and diminish after amputation by the absence of the influence. We can comprehend how the smaller vessels, taking the place of the trunk, and becoming the main supply, increase under that influence: and we then comprehend also, how in the instance of the varicose aneurism, the limb being imperfectly supplied with blood, (owing to the blood escaping by the side passage), it excites and solicits the trunk of the artery the more. So that, like the vessels of a growing part, the artery encreases in size and tortuosity. In this way of considering it, the hole in the side of the artery is the indirect cause of the enlargement: it reduces the supply of blood to the fore-arm; and the fore-arm, in its influence on the trunk which supplies it, excites that vessel in a manner which Dr. Hunter has finely illustrated by the comparison with the artery of a growing part.

If any one holds his hand above his head for a few seconds, he will be convinced that there is an accommodating power in the arteries, to the difficulty of the circulation; the arteries will be felt pulsating to the finger ends; while, in the other arm, if it be in a horizontal posture, there will be no pulsation, nor unusual sensation perceptible. I must suppose that if this position of the arm were to be continued, the excitement which the vessels have to activity would be followed by a permanent change in their curvatures; and that they would become like the arteries of the head.

I request my ingenious reader to try this simple experiment; and, when he has acknowledged the fact, to assign a reason for this change in the pulsation of the arteries of his fingers. He will, perhaps, say that it is the easy descent of the blood through the veins, which permits an easier discharge of the blood from the extremity of the arteries, and, therefore, a fuller contraction of their coats. Let him vary the experiment,—let him tie a cord round the arm, yet not so firmly as to stop the circulation, and hang the arm over the bed or sofa: here also the pulsation will be felt to be encreased, and from the same cause, viz. the difficulty with which the circulation is performed; an impediment is experienced in moving the blood upwards in the veins against the constriction of the cord, and the arteries increase their action to overcome it. I might state the matter in form of a question,—How is it that the circulation is equalized in the various postures of the body and limbs? How is it equalized during exercise, or during the peculiar positions and continued actions of artizans, or during the existence of tumors and morbid obstructions? Is it not because the arteries exercise a power adjusted to the difficulties opposed to their activity?

In these examples I have stated a few of the difficulties with which they will have to contend, who bestow the whole power of circulation upon the heart; difficulties too, which they encounter who maintain that a tortuous artery is a provision for retarding the circulation of the blood. If a reason can be given why the blood should be retarded in the uterus during gestation, I shall be inclined to acknowledge all the other instances to have no force.

To suppose that the tortuous form of the artery is an accidental consequence of the pressure of the blood, would be to admit an imperfection in the design of the animal economy, and to harbour a notion which must prevent us from arriving at a just and true estimate of the wisdom of the Creator. To consider the curve as design, and that the intention is to retard the course of the blood instead of increasing the force of the arteries, would be to suppose that mechanical obstructions were interposed, where, in fact, we find that there is a remarkable increase in the force of circulation, and a growth of the part rapid beyond example.

The very great confusion in which this subject, the circulation of the blood, has been left, is some apology for the easy admission of statements without proof. I have of late observed, with great surprise, the progress of an opinion that arteries are not muscular. Against the evidence of human anatomy, —against the analogy of the structure of inferior animals,—against the direct evidence of the senses, and on the mere ground that some chemist has thought he has discovered that there is no want of fibrine in the texture of arteries; an opinion is taken up that the arteries are not muscular. It really appears as if men were desirous of altogether disavowing and overturning the labours of the great men of our own country who have gone before them. I cannot imagine men possessed of any relish for philosophical enquiry, or capable of pleasure in witnessing the exertion of genius, thus disregarding the labours of Mr. Hunter upon this subject.

The arteries are fibrous, dilatable, contractile; and a certain proportion of this contractility depends on the life, and ceases with it.

The velocity of the blood in the different branches of the arterial system is not the same. We find parts subject to an encrease of arterial action; we cut into an inflamed part, and the blood flows with more velocity, than in the natural state of the body. The exercise of an organ in its function will produce in it a fuller pulsation; its arteries will be more active, and its blood will be driven further. If the uterus be examined during menstruation, it will be found to contain more blood, and to possess larger vessels. If the intestine of a dog be opened during the process of chylification, it will be much redder than at another time. How shall we account for the growth of one part of the body, and the decline of another, without admitting a partial encrease of action, and a partial diminution. How shall we explain the fact that we select a part that has been in activity to make a minute injection of its vessels, and that we cannot get the fluid to run into parts which have long ceased to be excited? As this partial action of arteries cannot be denied, we must also admit that it is their irritability, and their different degrees of excitement and growth which make the difference.

The power or effect of a natural action does not more depend on the muscular contraction, its rapidity and force, than on the entire and ready relaxation of its opponent muscles. Without this, the limb would be rigid in spasm, not powerful in its effects. To come nearer in the analogy to the arteries, the relaxation of the heart is quick and complete in proportion to its natural and lively contractions. This we see in the heart, and must imagine to take place in the artery. The phenomena which I have described, as exhibited in the change of the artery, authorise the conclusion, that when an artery is excited, it is not only excited to rapid and unusual contraction, but also to sudden and complete relaxation in the intervals of that action. Grant that the influence is to promote relaxation as well as contraction, and every thing is plain. We then see how an artery admits of partial increase of pulsation; how the carotid system, for example, will partake of excitement: then comes a beating of the artery in the neck, a pulsating pain of the temple, tension across the forehead, flashing of the face, animation in the eyes, flashing of light, and singing in the ears, while the hands and feet are cold. Then also the rapid growth of certain parts of the body beyond others can be explained when they encrease either in the natural or diseased state.

I shall here endeavour to state the argument shortly:

1. A tortuous artery is a more capacious artery. Hunter and Blumenbach, and others, have observed the diameter of the artery to encrease as it recedes from the heart; and this to be particularly the case in the vessels of the testicle and uterus, &c.

2. The artery being encreased in length and in calibre, it must contain more blood, and, therefore, act upon more.

3. If the muscular coat of an artery be greater the further it is distant from the heart, and if the muscularity of an artery be the

more the longer it is, so must the muscularity of a tortuous artery be greater than that of a straight one. The tortuous artery, therefore, acts with more force.

4. The further an artery is from the heart, and the nearer it approaches to its destination, the more it becomes under the influence of the part or organ; it is involved in the same nervous tissue with it; and subject to the same excitement. Therefore the power which the tortuous artery possesses, will be more under the influence of the part to which it goes.

5. The excitement of a hollow muscle does not consist merely in contraction, but in the free and perfect relaxation which follows the contraction.

The conclusion is, that a tortuous artery is more capacious, more active; that its activity is more under the influence of the part; that n its activity it dilates more freely, as well as contracts more powerfully. In other terms, an artery, in proportion to its tortuosity, becomes less dependant on the force of the blood transmitted from the heart more on the excitement of the organ which it serves.

Returning with these views to our subject of tortuous arteries, it will not appear paradoxical if we say that the tortuous arteries both retard and accelerate the blood. For as, by experiments on dead tubes, it appears that a curve retards the course of fluids, and, as it as certainly appears, that in the living frame a tortuous artery is employed to encrease the force of the circulation, we may conclude,—

1. That when the tortuous artery is not excited, it retards.

2. That when it is excited, it accelerates the flow of blood.

And now looking to the organs of the human body which have an occasional remission of their activity, or which have an occasional call for an increase of their function, we find that they are all remarkable for the tortuous form of their arteries.

1. The uterus in the interval of menstruation requires only to be kept alive; its vessels are in a quiescent state. But when the period returns, it swells, becomes more vascular, redder, an acme of arterial pulsation ensues, the menses flow, and then there is a subsidence of the action. If impregnation takes place, the excited action continues, the increased tortuosity becomes more obvious, and exhibits a singular congeries of twisted vessels. On delivery, the whole uterine system sinks again into its passive state.

2. The testicle in all animals is an organ of occasional activity. For the performance of its office there is required a sudden increase of vascular activity, while it is as obvious that this activity is not constant or uniform. It is an organ in a remarkable manner set aside

from the general tide and force of circulation, and is particularly inactive, unless excited.

Accordingly the vessels of the testicle are tortuous in an extraordinary degree. The artery comes from the aorta high in the abdomen, and runs a course at first straight, but, bye and bye, it forms certain curves; these turns, as the artery is traced downwards, become circles, and, as it approaches the testicle, it is so twisted as to form a body of a pyramidal shape, consisting entirely of convoluted vessels; and finally it dives into the body of the testicle, the branches being still tortuous.

3. I might here take the instance of the splenic artery, which is very remarkable for its tortuous form; and, it will be granted, that the parts to which it is sent, the stomach, the spleen, and pancreas, are occasionally excited; they are subservient to digestion; and, therefore, subject to temporary increase of action in the natural and healthy economy.

4. But, in truth, it holds universally that an artery becomes tortuous as it approaches its destination. Let us, for example, take two lymphatic glands, one seated near the heart, another in the thigh: in both, the branch of the artery which dives into the substance of the gland, advances to its destination by twisting and turning, and the curves, are the more remarkable the nearer it approaches to the gland. In the tortuous form of the arteries of the two glands no difference can be observed. Can we believe that the heart is made too powerful for the system, and that its impetus, even at the extremities of the arteries, requires to be counteracted by some mechanical hinderance?

Is it not obvious, on the contrary, that as an artery approaches the part to which it is destined, it becomes more under the excitement of that part? and that, in order to minister to the organ to which it is destined without disturbance of the general motion of the blood, it is made tortuous, and, consequently, more muscular and active.

Comparative anatomy affords a confirmation of what is here advanced from the human anatomy. In brutes the muscles of the most powerful action, as those of the jaws of the lion and tiger, are supplied with tortuous arteries. Undoubtedly those arteries, by the superior power they are capable of exerting, serve to continue the circulation and the supply of blood to the fibres. For the fibres and fasciculi would otherwise, during their state of action, compress the vessels, and diminish that force of circulation, on the continuance of which the irritability or power of the muscle depends.

An attempt has been made to connect the tortuous form of the arteries which supply the muscles of the tardigrade animals with the slow motion of their muscles. But the circumstance to be explained is not the slow motion, but the long continued action of the muscles of these animals. The animal, with such a construction of the circulating apparatus of the muscles of the anterior extremity, will continue hanging by the branch of a tree during the whole night.

From these views of the subject, a question naturally arises,—What purpose does the tortuous form of the arteries of the brain serve, and what is the use of the *rete mirabile?*

The tortuous form of the vessels of the brain in some measure cuts the organ off, and secures it against the irregularities of the circulation; such, for example, as that sudden impetus which the blood in the arteries receives from the violent exertion of the trunk and limbs, and which will be explained in the third division of this Essay. At the same time, the tortuous form of the arteries of the brain places them more under the influence of that organ, so as to measure the supply of blood according to the exercise of the function.

As to the *rete mirabile*, that convolution of vessels formed by the cerebral artery before entering into the brain of some brutes, it serves the same purpose, but in a superior degree. An animal with long legs, and, consequently, with a long neck, must have the circulation of the brain subject to sudden and remarkable changes, as it raises the head, or hangs it in grazing. By the rete mirabile the brain depends on its own excitement for its supply of blood, and becomes independent of the position of the head. An animal remarkable for the sudden changes from repose to activity, and for the highest degree of exertion when excited, (as the lion,) possesses, by this mechanism, both a means of saving the organ from the shocks and sudden changes to which its circulation is exposed during its extraordinary activity, and yet a means of sustaining the vigorous circulation in the brain to a degree commensurate to the state of animal excitement.

Am I not borne out in saying that physiologists have overlooked the most obvious things, to encounter extraordinary difficulties? The tree of the arteries presents the most simple explanation of the forces circulating the blood. Here we see branches of different lengths and curves, and which, therefore, receive the blood from the heart with different degrees of force. But this inequality is corrected by their own powers: for as they possess a second power, and, as that power is greater in proportion to their lengths, they equalize the circulation, giving to every part, whether near to or remote from the heart, its proportioned force of circulation. If the part to be supplied be near the heart, the impulse from the heart is greatest; if it be remote, the impulse from the arterial contraction is greatest.

Again, in supposing that the force of the heart moves the extremity of the toe loaded with a hundred pounds, they have forgotten that the weight of a few pounds will stop the pulsation at the groin. If they had thought of the tying of an artery with a hair, or of the compression of it with the point of the finger, or of the delicacy of the valves and coats, would the force of the heart ever have been estimated at one hundred and eighty thousand pounds? The calculation of the force exerted by the heart in raising a weight placed upon the foot has been a favourite theme: and if we could admit that the power of the heart was equal to the effect, we should be forced perhaps to admit the extravagant conclusions which have been drawn from this experiment. But it is altogether a delusion. I shall first state the fact and the form of the argument. When one leg is twisted over the other knee, and the foot is held suspended, a distinct pulsation is perceived in the toe, and the toe will pulsate and rise, although the foot be loaded with a hundred pounds. Now here the whole power of the heart cannot be exerted, for its force is divided to the head, to the arms, to the legs; so that, at the most favourable calculation, it is a fifth part of the natural force of the heart which moves the leg. In the next place, the leg is here as a lever of the third kind; the moving power is the artery behind the knee joint; it moves the weight upon the foot in proportion as its distance from the centre of motion in the knee joint is less than the distance of the centre from the weight. How much, therefore, must the weight of a hundred pounds be encreased in its pressure upon the pulsating vessel? Yet the vessel throws it up! the heart distending the vessel, with but a fifth part of its power, throws up this accumulated weight!! truly then the force of the heart is beyond calculation. What must it be at the aorta? What can withstand it? This consideration alone should have led to the re-examination of the presumed data, the grounds of this reasoning.

First, then, we find that at most a few pounds will stop the pulsation of the crural artery at the groin. In the next place we find, that if the knee be supported upon a small pad placed betwixt the ham-strings, or if the knee be suspended by grasping the condyles of the femur, there will be no pulsatory motion of the foot, although the leg hangs at right angles with the thigh; farther trials will show that the fleshy bellies of the muscles of the calf or ham must rest upon the knee to produce the effect contemplated. If the experiment be made with the arm, the same circumstances will be observed: when we rest the elbow on the table, and bend the fore-arm to a right angle with the arm, no pulsation will be seen; but if the flesh of the arm rest on the back of a chair, so as to compress the veins, and make the bellies of the biceps and triceps press against the support on which the arm is extended, then the hand and fingers will pulsate like the foot in the other instance. But if the arm be made to press in such a manner that the trunk of the artery is compressed, and not the bellies of the muscles, then there is no pulsation observable in the hand and fingers. It follows, that we are wrong in supposing the motion of the foot is owing to the popliteal artery changing from the curved towards the straight line; or in supposing that it is the attempt of the current of blood to force itself against the compressed artery. It is not the popliteal or the brachial artery which throws up the limb; it is the pulsation of the smaller arteries within the fleshy substance of the limb, that produces the motion.

This fact leads to a very different view of the subject; instead of estimating the power of the heart, we are induced to look to the arteries. The experiment being accurately made, will also prove that the pulsation of the carotids, and the motion of the foot, are not synchronous. If we divide the time of the pulse into three portions, we shall have the pulsation of the carotid in the beginning of the first period, the pulsation of the foot in the beginning of the second period, and the recommencement of the pulsation of the carotid in the end of the third period. This farther countenances the belief, that the motion of the foot proceeds from the smaller branches, and not from the pulsation of the trunk; a certain portion of time being required before the impulse from the heart reaches the extreme arteries. But a farther question arises here: when the impulse is conveyed along the artery, from the heart, is it assisted by the contraction of the artery, and is there a succession of contractions in the arterial coats from trunk to branch, and bearing an accurate relation to the time that this impulse is received. If this be the case, then must the pulsation in the extreme arteries be not solely that received from the heart, but an accumulated arterial impulse also.

But whether this be admitted or not, if it be granted that each of the small arteries possess a certain degree of power, however small; yet when we enumerate the branches of an artery in the belly of a muscle, and calculate the amount of their combined forces, we shall discover a source of power, commensurate to the effect we have witnessed in the elevation of the foot, even when loaded with an additional heavy weight.

PART III.

When we have persuaded ourselves that we have arrived at some just notions of the powers circulating the blood, and have in imagination placed the frame of the human body before us, and contemplated the various results from the circulation of a living fluid: our conception of these wonders is imperfect, until we see the body in activity, and witness the effects upon the blood, of the change from repose to exertion.

The instant that a man becomes animated, or starts into exertion, the motion of the blood is thrown into disorder. There is no longer the measured activity of the heart, and the gentle and equable motion of the lungs. The whole vital organs suffer the nature of a revolution. Is this an error or an imperfection in the frame-work? Far otherwise; out of this agitation, and seeming irregular violence, come additional means for sustaining the activity of the body. It is like those changes in nature, storms and tempests, and extremes of heat and cold, which seem the forerunners of misfortune, but which remove whatever is stagnant and noxious; preserving all nature in healthful activity.

The valves of the veins are provided for the exercise of the body; through them the pressure of the muscular frame-work, when employed in walking, running, leaping, or any sort of exertion, becomes a power additional to that of the heart and arteries in circulating the blood. While the veins are tubes, conveying back the blood which was sent out by the arteries from the heart, they are, from their capacity and their numbers, also reservoirs of the blood which moves through them languidly. The veins are compressible by the muscles: this compressibility is so far from being an imperfection in the apparatus of the circulation (an opinion too hastily received), that it is attended with the most happy result; since through this effect solely, there is ever preserved an equality betwixt the force and rapidity of circulation and the muscular exertions.

Without the valves of the veins, which hinder the blood from moving retrograde, the pressure of the muscles would not effect this purpose of throwing the blood in encreased quantity upon the heart; the blood would be forced by exertion to the extremities, instead of towards the centre of the circulation. The observations of those who preceded Harvey went thus far; and Fabricius distinctly says, that the valves of the veins were to prevent the blood from being forced outwards upon the extremities during exertion. They can bestow no additional activity, they only direct the impulse received from the muscles of the extremities towards the heart.

The heart assumes an activity proportioned to the blood which it receives; and the lungs, always in sympathy with the heart, partake of this activity and the respiration is encreased. The office of the lungs is to render the blood capable of supporting the life of the body, and in an especial manner the irritability of the muscles; now the motions of respiration are in proportion to the quantity of blood which has been compressed from the veins, and placed under the more active operations of the heart and arteries. It is thus that an activity is given to the circulation, and consequently the means of supporting the irritability of the muscles, in the proportion to its expenditure in exertions.

The circle of operations is in this succession; the muscles compress the veins; the heart is distended with blood; the lungs are excited by the state of the heart, the activity of the circulation and the respiration is thus promoted: and the effect is, that the circulation in the muscles is encreased, and their irritability thereby supported.

The action of the muscles has not only an influence in sending back the blood to the heart, but also in accelerating the flow of blood outwardly through the arteries. In performing an operation on an infant, or trying to suppress a hemorrhage from a drunk man, I have witnessed, with surprise, the additional force given to the jet of blood from an artery during the moment of exertion.

It is fortunate that we can have recourse to the account of experiments made by a man of veracity, instead of repeating hateful experiments on dying animals. When Hales was attempting to estimate the power of the heart by attaching glass tubes to the arteries of a horse, and admitting the blood to rise into the tube, he observed that an occasional variation took place in the length of the column of blood; and this not attributable to the force of the heart, but to the exertions of the creature. He saw, even in the moment of its expiring, that the blood rose remarkably in the tube; and that on stopping the nostrils of the animal, the blood rose five inches; that it rose considerably and suddenly on the animal drawing a deep inspiration.

Hales observed accurately, but he drew a wrong conclusion. He thought this additional rise in the column of blood was owing to the dilatation of the lungs, and the greater freedom with which the blood passed from the right to the left side of the heart. On the contrary, we know that, during a struggle, there is a greater difficulty in the circulation through the lungs. The true explanation of this effect, must be derived from the observation of the manner in which the heart and great vessels are guarded, by the tension of the membranes which are around them; and which tension is encreased in a remarkable manner during the violence of corporeal action; without which, indeed, the heart would be overpowered by the blood sent in upon it; and by which the additional force of the abdominal muscle and diaphragm, is still employed in accelerating the blood in the course in which it ought to flow.

In this review of the forces circulating the blood, by giving to the vessels, and to the membranes surrounding the heart, their due importance, the Author has somewhat diminished the value of the heart's action, and reduced it to the regulation of the general current of the fluids, and the action of the lungs in connection with the circulating system. When we reflect that the blood of some creatures circulates without a heart, and see acephali born without a heart, yet fully nourished, —and when we see the aortic system of fishes removed almost out of the influence of the heart, —and when we see that the heart of all animals is placed in juxtaposition, and in accurate sympathy with the lungs,—it is impossible to refuse assent to the proposition, that the arteries possess the chief power in circulating the blood through the corporeal system; and that the heart is rather the regulator than the prime and efficient cause of the circulation. And by this it is not only meant that its state of excitement and activity commands and draws after it the motion of the blood generally, but that it regulates the actions of the lungs, in exactly according with the state of the blood and the necessities of the system.

The Author has shewn that the irregularity in the demand of remote parts for blood cannot be answered by the acceleration or diminution of the heart's action; that the principal organs of the system have a provision for that partial encrease of activity in their vessels which does not disturb the general economy, nor call for the action of the heart. He thinks he has shewn that the object could not be effected by the encrease or diminution of the heart's activity; and that if the endowment and vital properties of the organs were entirely dependent upon the general force of circulation, and not on the capacity of their own system of vessels, to encrease or diminish the force of the blood: life would be held by a still more precarious tenure than it is: the vital action would interrupt the general system, and the agency of passion, and mental, and even corporeal activity, would disturb the economy of the organs essental to life.

For entering on this subject he has already offered the apology, that he felt himself obliged to do so by the nature of his daily occupations. But surely there is another and better reason in the nature of the subject itself. To ascertain the difference between fluids moving in pipes, and according to the laws of extended nature, and the circulation of fluids in the vessels of living beings, must be an important part of science. It is interesting to him who loves to take an extensive survey of nature, and very important to the student who is about to devote himself to the survey of animated nature, to perceive, by these proofs, that there are new principles and new laws to be studied. By the novelty of this enquiry, to some, it may prove the occasion of opening those sensibilities to the works of nature which, by habit of inattention, have been lost to things seen in the more familiar path of existence. To contemplate with the microscope the circulation of the blood in minute vessels, makes the head giddy, so surprising is the rapidity of the globules of blood; and on raising the head, and calmly considering the matter, the surprise does not cease: we have surveyed a new world, where the velocity and seeming impetus have no sufficient cause, and to which the laws of things hitherto familiar do not extend.

THE END.

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